

Production of N₂ Vegard-Kaplan and Lyman-Birge-Hopfield emissions on Pluto

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Abstract

We have developed a model to calculate the emission intensities of various vibrational transitions of N₂ triplet band and Lyman-Birge-Hopfield (LBH) band emissions in the dayglow of Pluto for solar minimum, moderate, and maximum conditions. The calculated overhead intensities of Vegard-Kaplan ($A^3\Sigma_u^+ - X^1\Sigma_g^+$), First Positive ($B^3\Pi_g - A^3\Sigma_u^+$), Second Positive ($C^3\Pi_u - B^3\Pi_g$), Wu-Benesch ($W^3\Delta_u - B^3\Pi_g$), Reverse First Positive, and LBH ($a^1\Pi_g - X^1\Sigma_g^+$) bands of N₂ are 17 (74), 14.8 (64), 2.4 (10.8), 2.9 (12.7), 2.9 (12.5), and 2.3 (10) R, respectively, for solar minimum (maximum) condition. We have predicted the overhead and limb intensities of VK (150-190 nm) and LBH (120-190 nm) bands of N₂ on Pluto for the New Horizons (NH) flyby condition that can be observed by Alice: the ultraviolet imaging spectrograph also known as P-Alice. The predicted limb intensities of VK and LBH bands peak at radial distance of ~2000 km with the value of about 5 (13) and 9.5 (22) R for solar zenith angle 60° (0°), respectively. We have also calculated overhead and limb intensities of few prominent transition of CO Fourth Positive bands for NH flyby condition.

Keywords: Pluto, Pluto Atmosphere, Ultraviolet observations, Upper atmosphere, New Horizon, Aeronomy, N₂ emission, Dayglow

1. Introduction

The atmosphere of Pluto is believed to be hydrodynamically escaping and extending to heights comparable to its radius (Krasnopolsky and Cruikshank, 1999; Strobel, 2008). Most of the information about the atmosphere of Pluto have come from the ground based occultation observations (Elliot et al., 2007; Young et al., 2008). Schindhelm et al. (2014) have provided a brief review of ultraviolet spectra observed from Pluto-Charon system by IUE. The data from these occultation observations are used to understand Pluto's atmosphere and are instrumental in the recent developments of general circulation models (Zalucha and Gulbis, 2012). Occultation studies have also shown that Pluto's atmosphere has undergone a surface pressure expansion by a factor of 2 from 1988 to 2002, followed by a stabilization from 2002 to 2007 (Elliot et al., 2007; Young et al.,

2008). The atmosphere of Pluto is similar to the Saturn's largest moon Titan: dominated by the N₂ (97-99%), followed by CH₄ (3-1%), and a trace amount of CO. Titan's extreme ultraviolet (EUV) dayglow spectra is dominated by N₂ Carroll-Yoshino (CY) Rydberg bands, while far ultraviolet (FUV) spectra is dominated by N₂ Lyman-Birge-Hopfield (LBH) and Vegard-Kaplan (VK) bands, and N and N⁺ lines (Ajello et al., 2008; Stevens et al., 2011). Pluto's dayglow spectrum is expected to be similar to that of Titan. Summers et al. (1997) have estimated the overhead emission intensities of possible airglow features in the atmosphere of Pluto, and calculated vertical column rates of various emission of N₂ and N, and N⁺ in airglow of Pluto.

New Horizons (NH) flyby of Pluto in July 2015 and will be the first visit of a man made object to Pluto. NH is carrying a host of instruments to understand the atmosphere and surface properties of Pluto. One of the instruments, ALICE: an ultraviolet imaging spectrograph (Pluto-ALICE or P-ALICE), is aimed at observing Pluto at EUV and FUV wavelength regions, and

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might observe various emissions from N_2 and its dissociated products mentioned above. We have developed the N_2 triplet band emission model for atmospheres of Mars, Venus, and Titan (Jain and Bhardwaj, 2011; Bhardwaj and Jain, 2012a,b). In the present study, we have extended the N_2 triplet band emission model to Pluto, and have added the calculation of LBH (singlet) band emissions. We have made calculations for solar minimum, moderate, and maximum conditions as well as for the New Horizons flyby conditions. These model calculations will help in making observations of Pluto's airglow by P-ALICE. In this study, we give volume emission rate and limb intensity of N_2 VK and LBH in the wavelength region 120–190 nm region, which lies in spectral range of P-ALICE (Stern et al., 2008). For the N_2 VK band major focus is given to transitions that lie between 150 and 190 nm region because emissions in wavelength region 120–150 nm constitute less than 1% of N_2 VK emission in wavelength region 120–190 nm (Jain and Bhardwaj, 2011; Bhardwaj and Jain, 2012a,b). We have also reported limb and overhead intensities for CO fourth positive bands.

2. Model

Model atmosphere of Pluto for solar minimum, moderate, and maximum conditions, and for NH arrival condition is taken from Strobel (2008). The mixing ratios of N_2 , CH_4 , and CO is taken as 0.97, 0.03, and 0.00046, respectively (Strobel, 2008). The mean Sun-Pluto distance is taken as 30 AU for solar minimum, moderate, and maximum conditions, and 33.4 AU for the NH arrival time prediction.

We have used the solar irradiance measured at Earth (between 2.5 to 120.5 nm) by Solar EUV Experiment (SEE, Version 10.2) (Woods et al., 2005; Lean et al., 2011) for solar minimum (F10.7 = 68), moderate (F10.7 = 150), and maximum (F10.7 = 250) conditions at 1 nm spectral resolution. For the NH flyby prediction (July 2015), the SEE solar flux is taken as on 1 May 2011, for which F10.7 = 106; the F10.7 solar flux index value is based on the solar cycle prediction made by Hathaway et al. (1994) (<http://solarscience.msfc.nasa.gov/predict.shtml>). The solar flux is scaled to the Sun-Pluto distance of 30 AU for solar minimum, moderate, and maximum conditions, and 33.4 AU for NH flyby predicted intensity calculations. The solar zenith angle (SZA) is taken as 60° unless otherwise mentioned in the text. All distances mentioned are radial distances measured from the centre of the planet.

The limb intensity of various airglow emissions is calculated as

$$I = \int \left[n_l(Z) \int_{E_{th}}^E \left(\frac{\int_{W_{kl}}^{100} \frac{Q(Z, E) U(E, E_0)}{\sum_i n_i(Z) \sigma_{il}(E)} dE_0 \right) \sigma_{il}(E) dE \right] dr, \quad (1)$$

where $n_l(Z)$ is the density of the l th gas at altitude Z , $\sigma_{il}(E)$ is the total inelastic cross section for the l th gas, $\sigma_{il}(E)$ is the electron impact cross section for the i th state of the l th gas, for which the threshold is E_{th} , $Q(Z, E)$ is the photoelectron production rate at altitude Z , W_{kl} is minimum excitation energy for k excited state of l th gas, r is abscissa along the horizontal line of sight, and $U(E, E_0)$ is the two-dimensional Analytical Yield Spectra (AYS), which embodies the non-spatial information of degradation process. It represents the equilibrium number of photoelectrons per unit energy at an energy E resulting from the local energy degradation of an incident electron of energy E_0 (Bhardwaj et al., 1990, 1996; Bhardwaj, 2003; Bhardwaj and Michael, 1999; Bhardwaj and Jain, 2009). While calculating the line of sight intensities of various LBH transition, we have taken absorption by N_2 and CH_4 into consideration, because below 140 nm, absorption by atmospheric gases can significantly affect the calculated limb intensities.

Electron impact excitation following XUV photoionization is the major source of N_2 triplet band emissions. The details of the model calculation of N_2 triplet band emissions is provided in our earlier studies on Mars (Jain and Bhardwaj, 2011), Venus (Bhardwaj and Jain, 2012a), and Titan (Bhardwaj and Jain, 2012b). In the present paper we have extended the model to include the N_2 LBH band emission calculation. Johnson et al. (2005) have reported the excitation cross section of $a^1\Pi_g$ state. Young et al. (2010) have measured emission cross section for the $a^1\Pi_g$ ($\nu' = 3$) – $X^1\Sigma_g^+$ ($\nu'' = 0$) and $a^1\Pi_g$ ($\nu' = 2$) – $X^1\Sigma_g^+$ ($\nu'' = 0$) transitions. The shape and magnitude of their relative emission cross section of $a(3,0)$ and $a(2,0)$ emission is consistent with the results of Johnson et al. (2005). Young et al. (2010) have not given emission cross section for entire LBH band system, though they suggested the emission cross section value of $6.3 \pm 1.1 \times 10^{-16} \text{ cm}^2$ at 100 eV. The electron impact excitation cross section of singlet (a^1 , a'^1 , w^1) states are taken from Johnson et al. (2005) and fitted analytically for ease of usage in the model (see Jain and Bhardwaj, 2011, and references therein). We have included radiative cascading between three lowest singlet states of N_2 ($a^1\Pi_g$, $a'^1\Sigma_u^-$, and $w^1\Delta_u$). For a state, vibrational levels which lie above $\nu = 6$ are not considered since these vibrational levels predissociate, and we

have excluded the cascade contributions from a' and w states vibrational levels which lie above $v = 6$ of the a state (Eastes, 2000; Eastes et al., 2011). The radiative transition data for the $a' \leftrightarrow a$, $w \leftrightarrow a$, and $a \rightarrow X$ are taken from Gilmore et al. (1992). For the $a' \rightarrow X$ transition, lifetime of 17 ms is taken for all vibrational level (Eastes, 2000). The collisional quenching rates of a , a' , w states are taken as described by Eastes (2000).

3. Results

The volume emission rates of vibrational transitions of various triplet and LBH bands of N_2 on Pluto are calculated for the three solar conditions. Figure 1 shows the volume emission rates of N_2 VK (150–190 nm) and LBH (120–190 nm) bands for solar moderate condition at $SA = 60^\circ$. Total emission rates of N_2 VK and LBH bands are also shown in the figure. Emission rates of

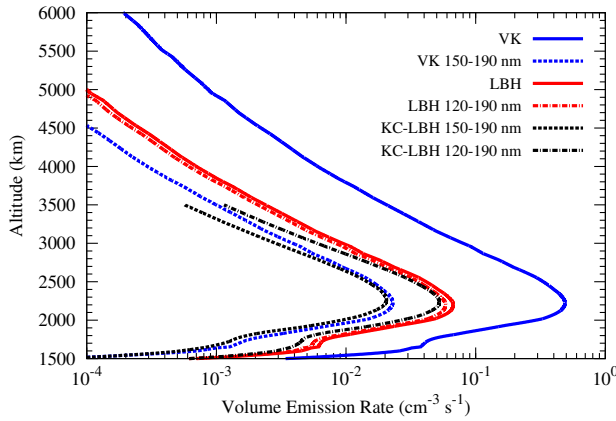


Figure 1: Calculated volume emissions rates of N_2 VK (total), LBH (total), N_2 VK (150–190 nm) and LBH (120–190 nm) bands for solar moderate condition at $SA = 60^\circ$ and Pluto-Sun distance of 30 AU. Black curves show the emission rate calculated using the M1 model atmosphere of Krasnopolsky and Cruikshank (1999) for VK (150–190 nm) and LBH (120–190 nm) bands.

both VK (150–190 nm) and LBH (120–190 nm) bands peak at radial distance of about 2200 km, with a value of 0.02 and 0.06 $\text{cm}^{-3} \text{s}^{-1}$, respectively. Table 1 shows the total height-integrated overhead intensity for Vegard-Kaplan (VK) ($A \rightarrow X$), First positive ($B \rightarrow A$), Second Positive ($C \rightarrow B$), Herman-Kaplan (HK) ($E \rightarrow A$), $E \rightarrow B$, Reverse First Positive ($A \rightarrow B$), $E \rightarrow C$, and Lyman-Birge-Hopfield ($a \rightarrow X$) bands of N_2 at $SA=60^\circ$, for minimum, moderate, and maximum solar conditions. Since many bands of N_2 span a large wavelength region, the overhead intensities of VK and LBH bands in different wavelength regions are also given in

the Table 1. Summers et al. (1997) have calculated volume emission rates of various emissions of N_2 and N on Pluto for moderate solar activity condition at Sun-Pluto distance of 30 AU. Their calculated volume emission rates peaks at ~ 2000 km radial distance. For N_2 LBH bands, Summers et al. (1997) have calculated an overhead intensity of about 5.7 R for CH_4 mixing ratio of 5×10^{-4} . Our calculated overhead intensity of N_2 LBH is 4.9 R for solar moderate condition. The minor difference in the two studies may largely be due to the cross section for N_2 LBH band used in the two studies and the input solar flux model.

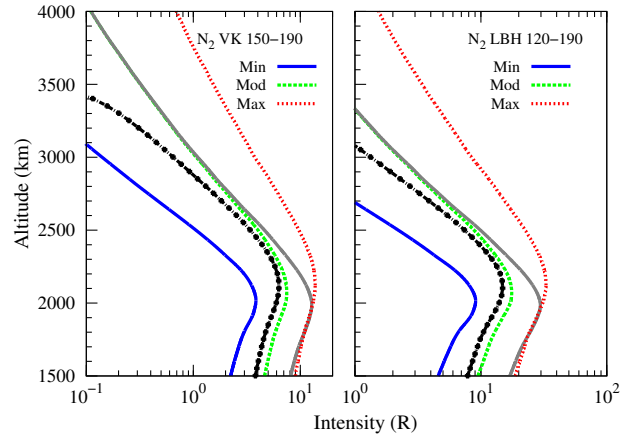


Figure 2: Calculated limb intensities of N_2 VK (150–190 nm) and LBH (120–190 nm) bands for solar minimum, moderate, and maximum conditions for $SA = 60^\circ$ and Pluto-Sun distance of 30 AU. Solid gray curve shows the intensity calculated at $SA = 0^\circ$ for solar moderate condition. Black curve with symbols shows the intensity calculated using M1 model atmosphere from Krasnopolsky and Cruikshank (1999) for solar moderate condition at $SA = 60^\circ$.

Figure 2 shows the calculated limb intensities of N_2 VK (150–190 nm) and LBH (120–190 nm) bands on Pluto for solar minimum, moderate, and maximum conditions. The limb intensity of N_2 VK (LBH) band peaks at radial altitude of about 2025, 2075, and 2125 km with magnitude of 3.8 (9.1) R, 7.4 (17.5) R, and 13.8 (32.9) R for solar minimum, moderate, and maximum conditions, respectively. Calculated limb intensities of N_2 VK and LBH bands at $SA = 0^\circ$ are also shown for solar moderate condition in Figure 2, which peak at 1995 and 1988 km with values of 12.8 and 29.7 R, respectively. We have also calculated limb intensities for other solar zenith angles. For $SA = 30^\circ$ (45°) the calculated limb intensities of N_2 VK (150–190 nm) and LBH (120–190 nm) bands peak at radial altitude of ~ 2000 (2020) km with values of 11.3 (9.6) R and 26.5 (22.6) R, respectively.

Table 1: Height-integrated overhead intensities of N₂ triplet and LBH bands emissions on Pluto for solar minimum, moderate, and maximum conditions at SZA = 60° and 30 AU, and the prediction for New Horizons flyby condition.

Band	Intensity (R)			
	Minimum	Moderate	Maximum	NH ¹ Prediction
<i>Triplet bands</i>				
VK ($A \rightarrow X$) (137–1155 nm)	17	37 (30.3) ²	74	25.3
137–190 nm	0.8	1.7 (1.4)	3.5	1.2
200–300 nm	5.9	13 (10.5)	25.8	8.8
300–400 nm	6.6	14 (11.8)	28.9	9.8
400–800 nm	3.7	8 (6.6)	16	5.5
1P ($B \rightarrow A$) (263–94129 nm)	14.8	32 (26.2)	64.4	21.9
2P ($C \rightarrow B$) (268–1140 nm)	2.4	5 (4.4)	10.8	3.7
$W \rightarrow B$ (399–154631 nm)	2.9	6 (5.1)	12.7	4.3
$B' \rightarrow B$ (312–37699 nm)	1.2	2.7 (2.2)	5.4	1.8
R1P ($A \rightarrow B$) (739–74175 nm)	2.9	6.3 (5.1)	12.5	4.2
$E \rightarrow A$ (207–303 nm)	3.3E-2 ³	7.2E-2 (5.9E-2)	0.14	4.9E-2
$E \rightarrow B$ (259–483 nm)	5.2E-3	1.3E-2 (9.3E-3)	2.3E-2	7.8E-3
$E \rightarrow C$ (1113–10127 nm)	1.9E-2	4.2E-2 (3.5E-2)	4.4E-2	2.9E-2
<i>Singlet bands</i>				
LBH ($a \rightarrow X$) (120–260 nm)	2.3	4.9 (4)	10	3.4
120–190 nm	2	4.3 (3.5)	8.8	3

VK = Vegard-Kaplan; 1P = First Positive; 2P = Second Positive, LBH = Lyman-Birge-Hopfield band, R1P = Reverse First Positive

¹Prediction for New Horizons arrival on Pluto (F10.7 = 106) for Pluto-Sun distance of 33.4 AU.

²Values in the parenthesis are overhead intensities calculated by using the M1 model atmosphere of Krasnopolsky and Cruikshank (1999) for solar moderate condition.

³3.3E-2 = 3.3×10^{-2} .

4. Discussion

4.1. Effect of model atmosphere

Krasnopolsky and Cruikshank (1999) have developed a detailed photochemical model of Pluto's atmosphere. Based on the occultation curve data, they have used two atmospheric models in their calculation for solar moderate condition and SZA = 60°; one assuming atmospheric tropopause at 1195 km (M1), and other assuming planet's surface at 1195 km (M2). In both models N₂ density is similar up to about 2000 km, and above this distance N₂ is higher in model M1. To evaluate the effect of model atmosphere on the calculated intensity, we have taken model atmosphere M1 from the study of Krasnopolsky and Cruikshank (1999) for the moderate solar activity condition. Figure 1 shows volume emission rates of N₂ VK (150–190 nm) and LBH (120–190 nm) bands calculated by using the M1 model atmosphere from Krasnopolsky and Cruikshank (1999) in addition to those using model atmosphere of Strobel (2008). The emission rate peaks at about same radial distance for the two model atmospheres, but the magnitude of emission rate at the peak is about 15% higher on using the model atmosphere of

Strobel (2008). Table 1 presents the overhead intensities calculated by using the M1 model atmosphere from Krasnopolsky and Cruikshank (1999).

4.2. Prediction

P-ALICE instrument is an imaging spectrograph aboard the New Horizons mission to Pluto/Charon and the Kuiper belt, with a spectral passband of 52–187 nm (see Stern et al., 2008, for details). The main objective of P-ALICE instrument is to perform spectroscopic investigations of Pluto's atmosphere and surface at EUV and FUV wavelengths. The spectral passband of P-ALICE is very similar to the Cassini-UVIS instrument, which observed both N₂ VK (150–190 nm) and LBH (120–190 nm) bands in the dayglow of Titan (Stevens et al., 2011). New Horizons flyby of Pluto will occur around July 2015. For the conditions similar (see Section 2) to NH flyby of Pluto, we predict the intensity of N₂ VK and LBH bands within the spectral passband of P-ALICE. With given baseline trajectory (cf. Guo and Farquhar, 2005), for a limb observation solar zenith angle variation may not be significant, hence we

have predicted limb intensities for fixed solar zenith angles of 0° , and 60° .

As discussed earlier, intensity of N_2 VK bands in 120–150 nm wavelength region is very small (0.02%), which make them difficult to observe in the dayglow spectra, and explain their absence in the dayglow spectrum of Titan (Stevens et al., 2011; Bhardwaj and Jain, 2012b). However, N_2 VK (150–190 nm) and LBH (120–190 nm) bands are observed on Titan (Stevens et al., 2011). For the NH flyby condition, the calculated overhead intensities of various triplet and LBH bands of N_2 is given in Table 1. The overhead intensities of N_2 VK (150–190 nm) and LBH (120–190 nm) bands are 1.2 and 3 R, respectively. Prominent emissions of N_2 VK and LBH bands in wavelength region 150–190 and 120–190 nm are given in Table 2. The N_2 VK (7-0), (8-0), and (9-0) are dominant emissions in wavelength region 150–190 nm with intensities of 0.21, 0.2, and 0.11 R, respectively. In 120–150 nm region, N_2 LBH (2-0), (3-0), (4-0), and (5-0) bands are the dominant emissions with intensities of 0.18, 0.22, 0.18, and 0.11 R, respectively. On Titan, our calculations suggest that intensities of N_2 VK (8-0) at 165.5 nm and (11-0) at 156.3 nm is about 2 to 3 orders of magnitude higher than that of CI 165.7 and 156.1 nm lines (Bhardwaj and Jain, 2012b), which were misidentified as possible source for carbon emissions near 165 and 156 nm (cf. Ajello et al., 2008; Stevens et al., 2011). On Pluto, we expect N_2 VK (8-0) and (11-0) bands intensities to be higher than that of CI 165.7 and 156.1 nm lines.

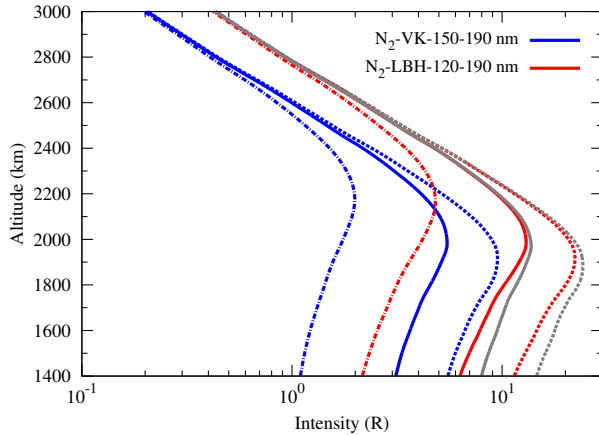


Figure 3: Predicted limb intensities of N_2 VK (150–190 nm) and LBH (120–190 nm) bands, for conditions similar to New Horizons flyby of Pluto in July 2015 (F10.7 = 106) at 33.4 AU (see text for detail). Solid curves are for $SZA = 60^\circ$, dashed curves are for $SZA = 0^\circ$, and dashed dotted curves are for $SZA = 90^\circ$. Gray solid and dashed curves show the calculated intensity of LBH (120–190 nm) band for optically thin ($\tau = 0$) condition at solar zenith angles 60° and 0° , respectively.

Table 2: Predicted height-integrated overhead intensities of N_2 VK, LBH, and CO fourth positive bands on Pluto for New Horizons flyby condition at $SZA = 60^\circ$. Prominent transitions between 120 and 190 nm, which lie in the spectral band of P-ALICE, only are given.

Band ($\nu' - \nu''$)	Band Origin nm	Intensity (R)	Band ($\nu' - \nu''$)	Band Origin nm	Intensity (R)
Vegard-Kaplan ($A^3\Sigma_u^+ - X^1\Sigma_g^+$)			Lyman-Birge-Hopfield ($a^1\Pi_g - X^1\Sigma_g^+$)		
3-0	185.3	2.1E-2	3-9	185.4	7.9E-2
4-0	180.8	4.7E-2	4-0	132.5	1.8E-1
5-0	176.5	8.2E-2	4-2	141.2	8.9E-2
5-1	184.1	4.3E-2	4-4	150.8	5.9E-2
6-0	172.6	1.3E-1	4-5	156.0	2.5E-2
6-1	179.8	4.5E-2	4-6	161.6	1.1E-2
7-0	168.9	2.1E-1	4-8	173.6	1.7E-2
7-1	175.8	3.7E-2	4-9	180.1	5E-3
8-0	165.5	2E-1	5-0	129.9	1.1E-1
9-0	162.2	1.1E-1	5-1	133.9	3.7E-2
10-0	159.2	5.1E-2	5-2	138.2	3.5E-2
11-0	156.3	2.2E-2	5-3	142.7	2.3E-2
12-0	153.6	1.1E-2	5-4	147.4	3.5E-2
Lyman-Birge-Hopfield ($a^1\Pi_g - X^1\Sigma_g^+$)			4-7	1674	4E-2
0-1	150.1	3.3E-2	5-6	157.6	3.9E-2
0-2	155.5	4.9E-2	5-8	169.0	2E-2
0-3	161.2	4.4E-2	5-9	175.2	3.1E-2
0-4	167.2	2.7E-2	6-0	127.3	5.4E-2
1-0	141.6	8.0E-2	6-1	131.2	5E-2
1-1	146.4	1.2E-1	6-3	139.6	3.6E-2
1-2	151.5	4.6E-2	6-5	148.9	2.6E-2
1-4	162.7	4E-2	6-7	159.2	1.4E-2
1-5	168.8	7.6E-2	6-8	164.8	1.6E-2
1-6	175.2	6.2E-2	6-10	176.9	1.9E-2
1-7	182.1	3.3E-2	6-11	183.5	1E-2
2-0	138.4	1.8E-1	6-3	139.6	3.6E-2
2-1	143.0	9.4E-2	6-5	148.9	2.6E-2
2-3	153.0	8.5E-2	6-7	159.2	1.4E-2
2-4	158.5	6.1E-2	6-8	164.8	1.6E-2
2-6	170.3	3.8E-2	6-10	176.9	1.9E-2
2-7	176.8	8.6E-2	6-11	183.5	1E-2
2-8	183.8	7.4E-2	CO Fourth Positive ($A^1\Pi - X^1\Sigma^+$)		
3-0	135.4	2.2E-1	0-1	159.7	2
3-1	139.8	1.4E-2	1-4	172.9	1.42
3-2	144.4	5.5E-2	2-2	157.6	1.1
3-3	149.3	6.3E-2	3-0	144.7	2.5
3-5	160.0	7.1E-2	4-0	141.9	0.83
3-6	165.8	4.3E-2	5-0	139.2	0.79
3-8	178.5	4.4E-2	5-1	143.5	1.36

We have also calculated overhead intensity and limb intensities of CO Fourth Positive ($A^1\Pi - X^1\Sigma^+$) band by electron impact excitation of CO and by fluorescent scattering. The electron impact emission cross section are taken from Avakyan et al. (1998) and fluorescence efficiencies for low solar activity conditions are taken from Tozzi et al. (1998). The overhead intensities of CO Fourth Positive (0,1; 159.7 nm), (1,4; 172.9 nm), (2,2; 157.6 nm), (3,0; 144.7 nm), and (4,0; 141.9 nm) emissions due to electron impact excitation (fluorescent scattering) are $1.4E-4$ (2), $1.1E-4$ (1.4), $1.2E-4$ (1.1), $3.6E-4$ (2.5), and $1.5E-4$ (0.8) R, respectively, for NH flyby condition (see Table 2).

Figure 3 shows the limb intensity of N_2 VK (150–190 nm) and LBH (120–190 nm) bands predicted for NH flyby condition. Calculated limb intensities of VK and LBH bands peak at the radial distance of 2000 km with values of ~ 5 and 10 R, respectively. For $SZA = 0^\circ$, the calculated intensity increases by a factor of 2 and the altitude of peak emission decreases by about 75 km and peaks at about 1920 km.

For P-ALICE to observe the N_2 LBH and VK bands in the dayglow of Pluto, it is very essential that emission

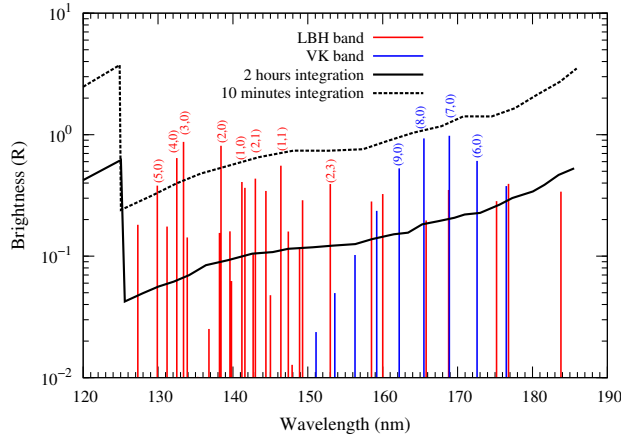


Figure 4: Predicted limb intensities (at $\text{SZA} = 60^\circ$) of various transitions of N_2 LBH (red), VK (blue), CO Fourth Positive (green) bands at 2000 km radial distance. Prominent emission lines of LBH, VK, and CO fourth positive bands are marked with vibrational transitions at top of them while symbol shows the predicted overhead intensities of the same transition (see Table 2). The expected P-ALICE SNR ~ 10 for 10-minutes (gray) and 2-hours (black) integrations at a range of 10^5 km is also shown in figure (taken from Figure 1 of Stern et al., 2008).

intensities must be higher than the sensitivity of the instrument, and also for a given observation, the signal to noise ratio (SNR) should be high enough to detect any meaningful data. In Figure 4, we present the predicted limb intensities of prominent transitions of N_2 LBH and VK, and CO fourth positive bands at 2000 km, along with expected P-ALICE SNR ~ 10 for 10-minutes and 2-hours integrations (taken from Figure 1 of Stern et al., 2008). The overhead intensities of N_2 LBH and VK, and CO Fourth positive bands are also shown in Figure 4, which shows that overhead intensity of CO fourth positive is higher than both N_2 LBH and VK bands. The sensitivity analysis given by Stern et al. (2008) is not related to viewing geometry and their estimated brightness features are for unresolved disk and limb. We found that for 2-hr integration, P-ALICE could detect a number of prominent transitions of N_2 LBH and VK bands, however for low integration (10-minutes) only a very few transitions are above SNR level of 10. This suggests that integration time for P-ALICE observations should be higher for it to detect bright emissions of N_2 LBH and VK bands.

4.3. Comparison with Titan's N_2 emissions

UVIS onboard Cassini spacecraft have observed N_2 VK and LBH bands emissions on Titan (Stevens et al., 2011). As mentioned earlier, we have developed model for N_2 emissions on Titan (Bhardwaj and Jain, 2012b).

Figure 5 shows the calculated limb intensities of N_2 VK (150–190 nm) and LBH (120–190 nm) bands in the atmospheres of Titan and Pluto for solar minimum condition ($F_{10.7}=68$) and $\text{SZA} = 60^\circ$. Figure 5 clearly depicts that N_2 emissions intensities on Titan is an order of magnitude higher than that on Pluto, reflecting closer proximity of Titan to Sun. The altitude of peak emissions on the Titan and Pluto differs by about 1000 km, which mostly due to the extended atmosphere of Pluto.

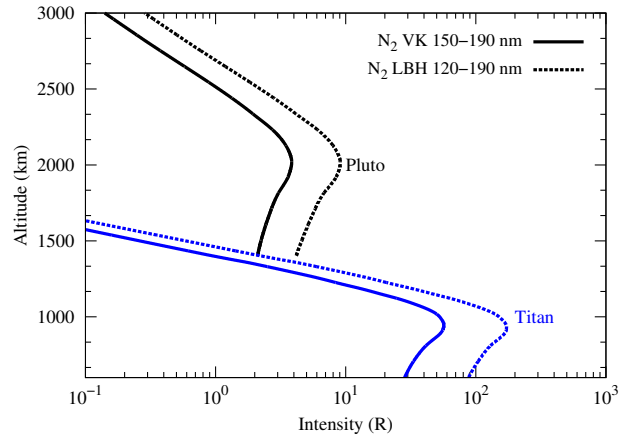


Figure 5: Limb intensities of N_2 VK (120–190 nm) and LBH (150–190 nm) bands on Titan (blue curves) and Pluto (black curves) for solar minimum conditions and for $\text{SZA} = 60^\circ$. The Sun-Titan and Sun-Pluto distances are taken as 9.7 and 30 AU, respectively.

5. Conclusions

We present the calculation of N_2 dayglow emissions in the atmosphere of Pluto. Our calculations predicted peak limb intensity of 5 (10) R for N_2 VK 150–190 (LBH 120–190) nm for the NH flyby conditions. However, the predicted intensities depend upon various input model parameters and the observed intensities would depend on conditions at the time of measurements. Based on our current understanding of Pluto's atmosphere for solar minimum and maximum conditions, variability for the peak limb intensity in the range 4 to 13.7 R (9 to 33 R) for N_2 VK (LBH) band is expected. Our calculation shows that overhead intensity of CO 4P bands for NH flyby condition is higher than that of N_2 VK and LBH bands. We hope that the NH mission will significantly improve our understanding of Pluto's atmosphere, and suggest conducting the limb observations of P-ALICE about 2000 km radial distance where airglow emissions peak and with enough integration time to detect prominent transitions of N_2 LBH and VK bands.

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